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OXYGEN BREATHING EQUIPMENT FOR HIGH ALTITUDE OPERATIONS

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13. ABSTRACT

In response to an urgent request from the US Army Northern Warfare Training Center (USANWTC), the US Army Land Warfare Laboratory (USALWL) initiated a program to develop and provide oxygen breathing equipment for high altitude rescue operations in Alaska. Commercial equipment currently used by civilian mountain climbing teams was investigated and the Robertshaw Controls Company oxygen system was selected and modified to meet the US Army requirements. After modification and testing USALWL purchased six systems, five of which were turned over to USANWTC for evaluation. These systems were used during two training missions on Mount McKinley and Mount Sanford. The results of the evaluation were favorable, although comments from participating units indicated a lighter weight system was desirable. From the medical viewpoint, additional modifications would be required for oxygen delivery to an injured rescuee. The five oxygen breathing systems are presently being held in readiness by USANWTC for possible use by high altitude rescue teams.

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PREFACE

On 15 April 1971 the US Army Northern Warfare Training Center received the mission for High Altitude Rescue Operations. The US Army Northern Warfare Training Center is located at an altitude of 1,266 feet and, due to the speed necessary for rescue operations, the rescue teams would not be acclimatized for high altitude operations. This would necessitate oxygen breathing equipment to prevent hypoxia. The US Army Land Warfare Laboratory was asked for assistance in providing a suitable oxygen system.

Acknowledgment is hereby given to the following individuals and company for their assistance and work performed in the development of the oxygen breathing apparatus:

Dr. F. Duane Blume
White Mountain Research Station
Bishop, California 93514

Messrs. Robert Stringer and Robert Hamilton
Robertshaw Controls Company
Anaheim, California 92803

DISCUSSION

Introduction

Existing evidence indicates that man can become acclimatized to an altitude of 17,000 to 18,000 feet if he lives in a rarified atmosphere. For high altitude rescue work, insertion of rescue teams must be rapid and personnel cannot be readily acclimatized. Therefore, oxygen breathing equipment is required above approximately 12,000 feet.

Previously, work on oxygen breathing equipment has been conducted in the commercial field for civilian mountain climbing teams and this report will discuss a modified Robertshaw Oxygen Breathing Apparatus, which was developed for the US Army Land Warfare Laboratory (USALWL) for field evaluation in Alaska by the US Army Rescue Teams.

Background

The Robertshaw Oxygen Breathing Apparatus was first used in the spring of 1971 when Norwan Dyhrenfurth led a group of the world's best climbers in an attempt to scale the formidable southwest face of Mount Everest. Due to relentless storms, personal conflicts and death, the summit was not reached, however, the oxygen breathing unit performed without difficulty.

Dr. F. Duane Blume, University of California, was the oxygen officer on the expedition, assigned to provide a portable oxygen system. It was through his efforts and the Robertshaw Controls Company, Anaheim, California, that the system described in this report was developed. Preliminary consideration of the problem by Dr. Blume indicated two possible approaches. One was the use of the closed-circuit principle tested by Bourdillon during the British expedition to Mount Everest in 1953 and the other was the application of the dilutor demand regulator, developed and used extensively for high altitude flying during World War II.

While the closed circuit apparatus permits the ultimate in efficient utilization of a given supply of oxygen, the equipment is bulky and mechanically complex. It also requires the use of a carbon dioxide absorbent which must be renewed periodically. Finally, should the oxygen supply fail while the unit is in use, the oxygen concentration in the circulating gas can actually fall below that in the ambient air without the wearer becoming aware of the situation.

The USALWL development effort was accordingly directed toward exploration of the dilutor demand regulator principle. The Robertshaw Controls Company had developed a miniaturized dilutor demand regulator which is in wide operational civilian and military use. Mr. Robert Hamilton of Robertshaw worked very closely with Dr. Blume on the final design.

Description of Oxygen Breathing Apparatus

1. Dilutor Demand Regulator

The most important component of the system is the Robertshaw regulator. When used by aviation personnel, these regulators are designed to simultaneously draw ambient air into the mask through an orifice in the regulator, and pure oxygen from a tank through a demand valve in the regulator. A passive aneroid valve controls the size of the ambient air orifice making it directly proportional to the barometric pressure. Therefore, as the altitude increases the ambient air orifice is automatically made smaller and the individual breathes a greater proportion of pure oxygen. The dilutor demand system thus accomplishes two things; one, it utilizes the available oxygen at the operating altitude while maintaining a near sea level partial pressure and two, this utilization of the available oxygen reduces the amount of bottled oxygen required.

The Robertshaw Controls Company undertook the redesign of their regulator to meet the specifications of Dr. Blume. The modifications ultimately resulted in a regulator which eliminated the emergency full-flow oxygen feature of the original and substituted four click-stop ambient air orifices for the aneroid valve. This substitution was necessary because the aneroid valve lacked sufficient sensitivity to the barometric pressure. The orifices, numbered one through four, can be selected by the climber to provide him a minimum ppO_2 (partial pressure of oxygen) of 80 Torr[a] at any elevation up to the summit of Mount Everest. Each of the settings correspond roughly to 2,000 foot increments in an altitude between 22,000 feet and 30,000 feet. This ppO_2 of 80 Torr is the level of oxygen partial pressure required for individuals operating at altitudes up to 17,000 or 18,000 feet.

By selection of the proper setting, sufficient pure oxygen is added to the ambient air to maintain an equivalent altitude range of sea level to 5,000 feet. This corresponds to an oxygen partial pressure of 160 Torr at sea level to 130 Torr at 5,000 feet. Setting No. 1 is used between altitudes of 10,000 and 14,000 feet, No. 2 between 14,000 and 17,500 feet, No. 3 between 17,500 and 20,000 feet and No. 4 setting is utilized above 20,000 feet. The oxygen partial pressure versus altitude for the various settings is graphically illustrated in Figure 1.

The lower diagonal line for each of the three click-stops on the regulator settings gives ppO_2 as a function of the ambient barometric pressure when the individual's inspiratory minute volume is 20 liters per minute, which represents mild activity. The upper diagonal line gives the ppO_2 when the inspiratory minute volume is 40 liters per minute, which is typical of moderate exercise. The dashed horizontal lines at ppO_2 values of 160 and 130 Torr represent the ambient oxygen partial pressures at sea level and 5,000 feet altitude respectively. It may be seen that the

[a]Torr = 1 mm. Mercury

regulator not only effectively keeps the ppO_2 at the equivalent of sea level to 5,000 feet, but that it has the additional feature of providing a higher ppO_2 at increased ventilatory rates.

2. Cylinder Assembly

The oxygen cylinders used in this application were of steel construction (Walter Kidde Corporation) with a 1,200 liter STP (Standard Temperature and Pressure) capacity at 3,000 psi. The cylinder weighs 16 pounds when fully charged, it is 5.4 inches in diameter and is 21.9 inches long (including valve). The cylinder valve has a standard CGA 540 oxygen valve connection and can be filled by any station equipped to fill breathing oxygen. Figure 2 shows the duration time of a cylinder as a function of the inspiratory minute volume at each of the three click-stop settings of the dilutor demand regulator. In practice, the oxygen flow rate, and the cylinder duration time, would be strictly proportional to the integrated inspiratory minute volume of the individual. Therefore, considerable oxygen economy is achieved automatically.

3. Robertshaw On-Off Reducer

The pressure reducer is a specially modified on-off reducer which is designed to provide a gas pressure reduction from 3,000 psi at the tank to 60-70 psi at the outlet. This on-off reducer weighs 17 ounces. The tank connector for the reducer consists of a brass fitting which has two brass bars welded to it which provides handles for manual attachment. A 0 to 3,000 psi pressure gauge is mounted on the reducer to indicate the quantity of oxygen in the cylinder. An auxiliary port is added to the reducer to permit the insertion of a slip-ring hose connector which can provide a constant flow of one liter per minute of oxygen for a sleeping mask. A section of reinforced silicone rubber tubing 4 feet long, 7/16 inch O. D., 1/8 inch I. D., and weighing 6 ounces (including metal fittings) is used between the reducer and the dilutor demand regulator to supply the latter with oxygen at 60-70 psi. Silicone rubber tubing was used because the Mount Everest expedition found that polyurethane tubing does not remain flexible in extreme cold, whereas silicone rubber will retain flexibility in the temperature range of -60°F. to -70°F. below zero.

4. Face Mask

The mask chosen was a standard A-14 mask made of silicone rubber (Sierra Engineering, P/N 500-254). Various problems associated with moisture accumulation and icing are of prime concern when using a face mask during cold temperatures. The small amount of dead space in the mask and the position of the expired air valve minimize the problems of moisture accumulation and icing within the mask. However, the mask was flexible enough to permit crushing by hand to free what little ice there was in the exhaust valve and port.

5. Sleeping Mask

The sleeping mask consisted of a molded plastic mask (Ohio Medical Company, P/N 304-5076) with a five foot length of polyurethane tubing fitted with a slip-ring insert connector for attachment of the mask to the on-off reducer. The reducer provides a continuous flow rate of one liter per minute of oxygen.

6. The total oxygen system weight is 18.5 pounds. The complete system is shown in Figure 3.

Development Testing

Physiological testing of the equipment was conducted in a low pressure chamber at the University of California by Dr. Blume. The tests consisted of having the test subject prepared with ECG electrodes for measuring heart rate, an A-14 face mask which had a miniaturized oxygen electrode incorporated into it was connected to a 50 psi oxygen supply line. The miniaturized oxygen electrode is used to continuously sense ppO_2 during the test. Dr. Blume was seated on a Quinton bicycle ergometer in the chamber. When the desired test altitude was reached in the chamber, the heart rate and ppO_2 were recorded under the following conditions: (1) The subject at rest. (2) During a standard 800 kpm[b] exercise for five minutes. (3) And, during recovery after the exercise. Chamber air was monitored by means of a Thermo-Lab Instruments Company Thermax Probe.

A typical test is shown in Table 1. In this test, a simulated altitude of 25,200 feet was attained. Because Dr. Blume is the resident scientist at the White Mountain Research Station, he has acquired a substantial degree of high altitude acclimatization.

TABLE 1. LOW-PRESSURE CHAMBER PERFORMANCE TEST

Exercise (kpm/min)	Time (min)	Heart Rate (beats/min)	ppO_2 (Torr)
Rest	0	80	98
Rest	1	80	95
Rest	2	84	98
Rest	3	80	95
800	4	106	100
800	5	120	100
800	6	128	100
800	7	132	102
800	8	132	102
Rest	9	104	100
Rest	10	92	100
Rest	11	100	100
Rest	12	88	98
Rest	13	88	98
Rest	14	92	99
Rest	15	88	98

[b]kpm = kilopond meters/minute

FIELD EVALUATION

The US Army Northern Warfare Training Center conducted two training missions, one on Mount McKinley and the other on Mount Sanford. During each mission, the oxygen breathing systems were used by various personnel. It should be noted these systems were not used for life support. The primary function was to determine the suitability of the oxygen breathing systems for potential use in an emergency mountain rescue. Observations were made on the weight of the system, ease of breathing, communication problems, duration of oxygen supply, freeze-up of valves, etc. These observations and comments are contained in the After Action Reports contained in the List of References.

RESULTS

The most apparent shortcoming of the oxygen breathing system is the weight. This could be reduced considerably by substituting an aluminum lined fiber glass oxygen bottle for the current standard bottle. The US Army Land Warfare Laboratory has made a cursory investigation of this type bottle but has not conducted any tests of hardware. Several individuals expressed a need for a harness which would give the individual a means of carrying the oxygen system separate from their pack. Because communications were difficult through the mask, it was necessary to remove the mask for talking and giving commands. The mask was attached to a cold weather "skull cap" by snaps. A need for a faster release system was expressed (particularly when wearing gloves) or possibly a mask that would allow communication without the removal of the mask. Several persons used the sleeping mask satisfactorily, however, one person removed the mask and inserted the oxygen tube into the sleeping bag with good results. There was one report of mask valve freeze-up which was solved by the person crushing the mask with his hand. During the Mount McKinley exercise, the oxygen breathing system was used several times to alleviate mountain sickness and acute discomfort (headaches, nausea, etc.), and in one instance is credited with saving a party member's life. Without exception, the Robertshaw Oxygen Breathing System was considered by participating personnel to be a valid approach for use in high altitude rescue work by specially trained teams.

From the standpoint of the victim or victims to be rescued, the system has one major drawback and that is the inability of the system to deliver oxygen at high flow or high concentrations. An unconscious man, a person with a severe rib fracture, certain thoracic penetrating injuries, or a person with respiratory arrest, may be unable to spontaneously breathe deeply. The demand system assumes a man under waking, working conditions, and the valve does not open while sleeping and shallow breathing is prominent.

In summary, the Robertshaw Oxygen Breathing System is an excellent item of equipment for high altitude rescue teams but should be reduced in weight by the substitution of a lightweight oxygen bottle.

CONCLUSIONS

The Robertshaw Oxygen Breathing System is acceptable for the functioning mountaineer, but inadequacies are seen with its use with an unconscious person or persons incapable of taking deep breaths.

LIST OF REFERENCES

1. US Army Northern Warfare Training Center, Fort Greely, Alaska, "After Action Report - Operation Celtic Summit", 1 August 1972.

2. US Army Health Clinic, Fort Richardson, Alaska, "Medical Annex to Operation Celtic Summit", 30 August 1972.

3. US Army Northern Warfare Training Center, Fort Greely, Alaska, "After Action Report, Celtic II", 26 September 1972.

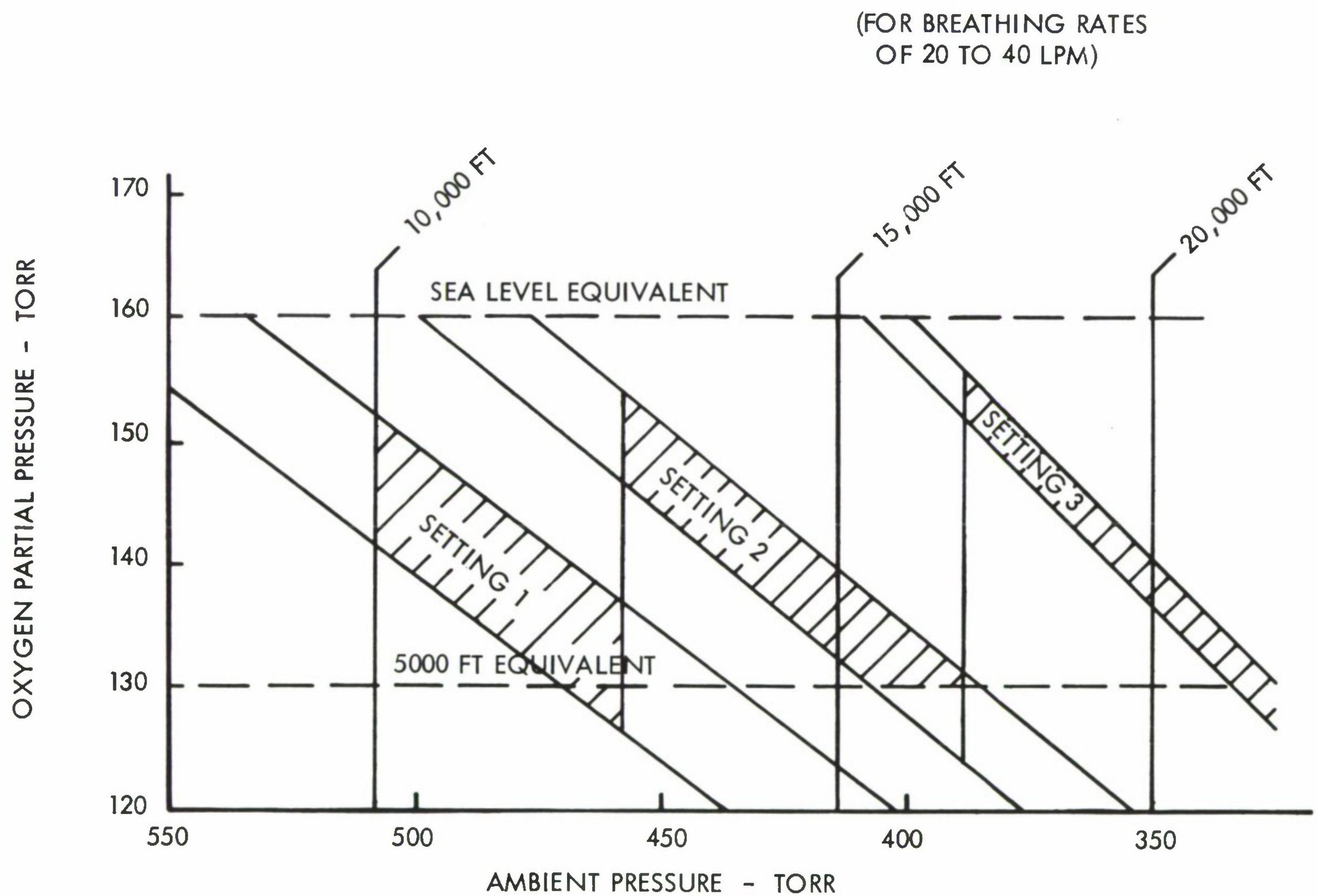

FIGURE 1. OXYGEN PARTIAL PRESSURE VS. ALTITUDE

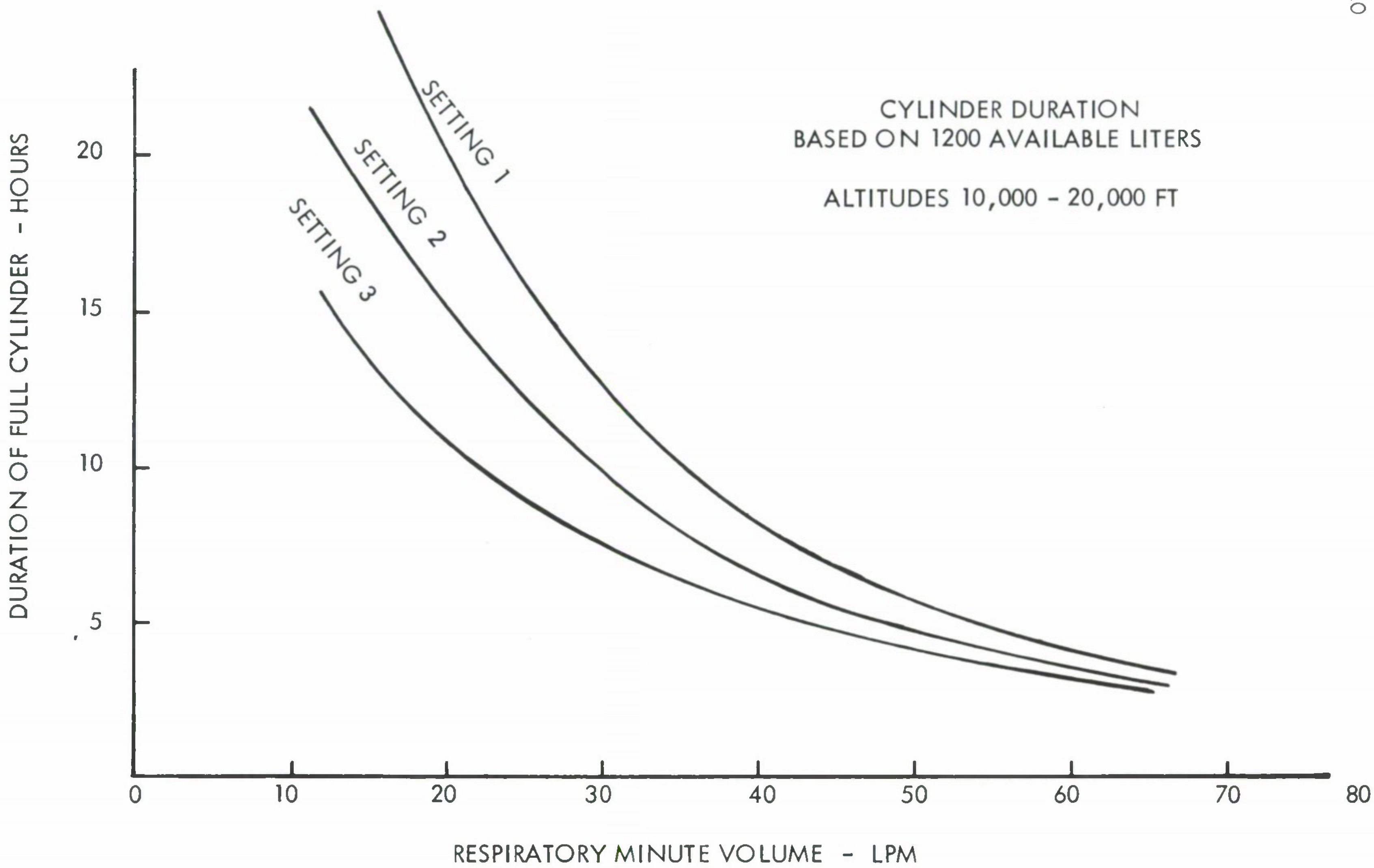

FIGURE 2. CYLINDER DURATION

FIGURE 3. OXYGEN BREATHING SYSTEM

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